# FOOD SAFETY HANDBOOK FOR HYDROPONIC LETTUCE PRODUCTION IN A DEEP WATER CULTURE (D.W.C)

A Project Paper

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Professional Studies in Agriculture and Life Sciences

Field of Horticulture

Controlled Environment Agriculture (C.E.A)

by

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# BIOGRAPHICAL SKETCH

My introduction to college all started when my former boss asked me what I had planned for my future. I responded I was not smart enough to attend college. Somehow, he convinced me to think about it. A visit to Cortland, New York with him would change my life and create a path for me to embark on something new. Fast-forward, its six years later and I have just a couple more days left as a graduate student. This journey has been my greatest challenge to date, but I have endured, developed new skills, and learnt so much. Now fully embracing this new life.

It may seem strange to others, but being an immigrant, first-generation, parent and working two-jobs while attending university has molded me. Know I am not finished yet as I promised myself to be the first in my family to do the Ph.D. journey and I plan to keep going. What has this journey been like? I now have a GED, an associate's, a bachelor's and soon a Master's degree. To complete this journey is important. As a native of a developing country its only one in every 100 people that has a graduate degree or even  a Ph.D.

So, what this means from a personal perspective, I will be the first person in my family to reach a master's in professional studies. Having this higher level of education is a high distinction for my family, community and to a greater extent the benefit of my home country. It is regrettable to say that it is the only way you can be truly recognized and admitted into the social class of the elites. But that is not my goal. There are socioeconomic conditions affecting my home country as it is a developing country which relies of its foreign exchange from tourism. This means people are out of a job, unemployed, and living on whatever means they can. Know it is a long road ahead, but I have reached this far and cannot turn back.

# DEDICATION

This publication is dedicated to the challenges I have met on this journey called LIFE. It is my hope that information contained in these pages will help to address the major challenges in Food Safety of indoor agricultural production systems.

Thank you, grandma, and happy 90th birthday today August 14th, 2019. You have been my number one supporter on this journey in college.

ACKNOWLEDGMENTS

Thank you to the Cornell University Controlled Environment Agriculture for the guidance to develop this Food Safety Handbook. This handbook has been specifically designed to provide a foundation of Good Agricultural Production Practices in Raft system Deep Water Culture (DWC) system with knowledge that includes the emphasis on hydroponic lettuce production in a greenhouse-controlled environment.

Thank you to my parents, family, and close friends who at some point supported this journey.

Thank you, Neil Mattson, for being so humble, knowledgeable, and diligent. You are a great advisor and I look forward in collaborating with you in the future.

Thank you to my dear friend Matthew Moghaddam for pushing me and encouraging me when the challenges presented themselves.

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Finally, thank you grandma for the inspiration, support, and encouragement. Because of you I was able to take this journey of tertiary education. Happy 90$^{th}$ birthday for August 14$^{th}$, 2019.

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| | | |
|---|---|---|
| A | Area | Square feet or Square Meter. |
| CEA | Controlled Environment Agriculture | Producing plants in greenhouse or other environmentally controlled space. |
| CDC | Centers for Disease Control and Prevention | |
| DO | Dissolved Oxygen | |
| DWC | Deep Water Culture | |
| EC | Electrical Conductivity | |
| FSMA | Food Safety and Modernization Act | |
| FDA | Food & Drug Administration | |
| PSE | Penn State Extension | The Pennsylvania State University |
| GAP | Good Agricultural Practices | |
| GHP | Good Handling Practices | |
| IPM | Integrated Pest Management | |
| PSR | Produce Safety Rule | |
| SOP | Standard Operating Procedure | |
| USDA | United States Department of Agriculture | |
| SFSP | Standard Food Safety Parameters | |

## CHAPTER ONE

# Food Safety and FSMA's Produce Safety Rules

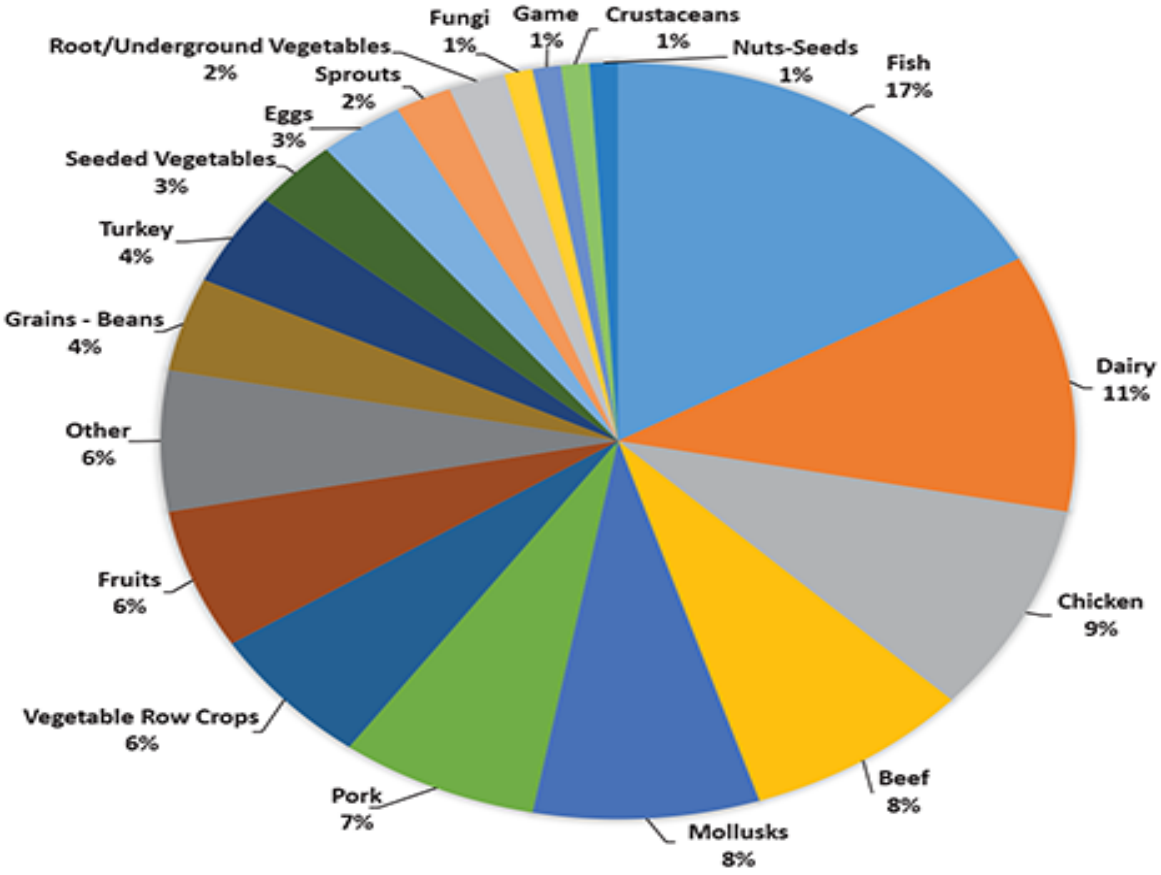
### 1.1 Food Safety and Food-Borne Illnesses

The U.S. Center for Disease, "Foodborne illness is a common, costly- yet preventable-public health problem". Therefore, as agricultural producers it is important to understand the role you play in this vital link between illness in people and the food systems (CDC, 2018). Historically, the U.S. Food and Drug Administration (FDA), and the United States Department of Agriculture (USDA) Food Safety and Inspection Service collaborate at the federal level to create initiatives to ensure and promote food safety. Additionally, their objectives and operations are supported by the State and local health departments, and most importantly the food industry. Through these combined efforts and collaborations consumers can ensure they have access to the best quality food.

### 1.2. Facts About Consumer Related Illnesses

With consumers being the final link in the Food Safety chain, it is important to understand why these efforts are created. The US Federal government states, "each year there are about 48 million cases of foodborne illness'' (FDA, 2019). According to the CDC it is estimated that 1 in 6 Americans get sick from contaminated foods or beverages each year, and approximately 3000 die (CDC, 2018). As consumers it is important to understand the various food borne illnesses and what to do if a situation arise. The CDC has a general list of these pathogens and further states, "these major pathogens are frequently transmitted by food contaminated by infected persons" (CDC,

2017). In figure 1.1 the CDC National Outbreak Reporting System for 2009-2016 listed the foods that sickened people in outbreaks with a single know source.




*Source: CDC National Outbreak Reporting System, 2009–2016*

Figure 1.1. Food that Sickened People in Outbreaks with a Single Known Source
Source: https://www.cdc.gov/foodsafety/cdc-and-food-safety.html

### 1.3. Challenges - Food Borne Outbreaks in Agriculture

In a hydroponic vegetable production system, it is important to first understand how these outbreaks are caused and their sources. In a farming or food production system there are on-farm sources of contamination such as; soil, people, manure, livestock, pets, wildlife, and unclean water (PSE, 2014). Although, all these contaminants are important in the food safety system, in a hydroponic operation a large focus is the contamination of agricultural water. Here the factors are how it is used in the production processes, the quality of the water, and its origin source, for example: well, rain, natural aquifers, or municipal sources. The aim of this handbook is to analyze and apply the Produce Safety Rule to a greenhouse system producing lettuce in a Deep-Water Culture System (DWC). In the Produce Safety Rule requirements contaminated agricultural water is a major concern in DWC hydroponics systems; other contaminants are still significant; they are mentioned briefly, but further information is available on the CDC webpage. (see FDA contaminants). The other contaminants although significant to agricultural production, are not the focus in the handbook.

### 1.4. Food Hazards

Food hazards results in major foodborne illnesses associated with food production systems. Foodborne illness (commonly known as food poisoning) is often caused by consuming food contaminated by bacteria and/ or toxins, parasites, viruses, chemicals, and or other agents (FDA, 2019). As in other agricultural production systems, a DWC hydroponic production food system is affected by three (3) categories of hazards. According to the FDA, a hazard is, “a biological, chemical, or physical agent that is reasonably likely to cause illness or injury in the absence of its

control" (FDA, 2017). Hydroponic operations are most commonly used in a Controlled Environment Agriculture (CEA) structure such as a greenhouse, protective enclosure, or hoop house, or warehouse farm. Nevertheless, CEA facilities will differ, so a respective food safety plan is dependent on its production systems and facility operations.

### 1.5. Cause of Illnesses

Every food safety outbreak is different and is caused by some type of hazard. The three (3) main hazards are biological such as (foodborne pathogens), chemical, and physical. The FDA states, "Foodborne illness occurs when people eat or drink food or beverages contaminated with pathogens, chemicals, or toxins" (FDA, 2019). It is to be noted foodborne pathogens are a major source of contamination associated with the use of agricultural water. See below for an overview for these hazards.

### 1.6. Biological Hazards

According to the FDA, biological contaminants cover a broad range of contaminants including both bacterial and viral pathogens. Under the Animal Feed Contaminants program, biological contaminants that are routinely monitored and detected include Salmonella spp., L. monocytogenes, and pathogenic E. coli. These bacterial pathogens may present a hazard to animal health by consumption of animal food, and to human health by consumption of animal-derived

human food, or by exposure to a contaminated animal food that can cause human disease (FDA, 2019).

### 1.6.1. Bacteria

According to the FDA's Outbreaks of Foodborne Illness webpage, "foodborne pathogens such as bacteria and viruses are the most common cause of food poisoning" (FDA, 2019). The three most common bacteria are of the top five (5) key foodborne pathogens listed here:

- Salmonella
- Escherichia coli (E. coli O157:H7)
- Listeria monocytogenes
- Cyclospora
- Hepatitis A

### 1.6.2. Foodborne Pathogens

For agricultural water, the associated foodborne pathogens such as Salmonella, E. coli O157:H7, and Listeria monocytogenes will be discussed in this handbook. The FDA's Bad Bug Book is a

recommended resource to learn more on Foodborne Pathogenic Microorganisms. See information here: https://www.fda.gov/food/foodborne-pathogens/bad-bug-book-second-edition (FDA, 2017).

### 1.6.3. Salmonella (Salmonellosis)


Image 1.1. Salmonella
Source: https://phil.cdc.gov/Details.aspx?pid=16877

According to FDA's scientific definition, Salmonella are a group of bacteria that can cause gastrointestinal illness and fever called salmonellosis. Salmonella can be spread by food handlers who do not wash their hands and/or the surfaces and tools they use between food preparation steps, and when people eat raw or undercooked foods. Salmonella can also spread from animals to people. People who have direct contact with certain animals, including poultry and reptiles, can spread the bacteria from the animals to food if they do not practice proper hand washing hygiene before handling food. Pets can also spread the bacteria within the home environment if they eat food contaminated with Salmonella (FDA, 2019).

Table 1.1. Salmonella information
***Sourc***e: https://www.foodsafety.gov/print/pdf/node/14?id=salmonella-table

| | |
|---|---|
| Sources | • Food: A variety of foods have been linked to Salmonella, including vegetables, chicken, pork, fruits, nuts, eggs, beef, and sprouts.<br>• Animals and their environments: Particularly reptiles (snakes, turtles, lizards), amphibians (frogs), birds (baby chicks) and pet food and treats. |
| Symptoms | Diarrhea, fever, stomach cramps, vomiting |

| | |
|---|---|
| Prevention | • Avoid eating high-risk foods, including raw or lightly cooked eggs, undercooked ground beef or poultry, and unpasteurized (raw) milk.<br>• Wash your hands after contact with animals, their food or treats, or their living environment. |

### 1.6.4. Escherichia coli or E.coli O157:H7

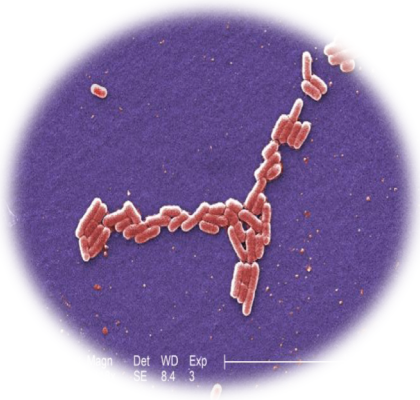


Image 1.2 E. coli O157:H7

Source: https://phil.cdc.gov/Details.aspx?pid=10070

According to FDA's scientific definition, E. coli O157:H7 – Escherichia coli (abbreviated as E. coli) are mostly harmless bacteria that live in the intestines of people and animals and contribute to intestinal health. However, eating or drinking food or water contaminated with certain types of E. coli can cause mild to severe gastrointestinal illness. Other types microbial pathogenic (illness-causing) E. coli strains, such as Shiga toxin-producing E. coli (STEC), can be life-threatening.

Primarily wildlife, livestock, and humans are occasional carriers of pathogenic E. coli and can contaminate meats and food crops. Contamination occurs when feces contacts food or water. Human carriers can spread infections when food handlers do not use proper hand washing hygiene after using the restroom. Pets and petting zoos can also cause infections to people if the animals infected with pathogenic E. coli (FDA, 2019).

Table 1.2. E. coli (Escherichia coli) information Table
Source: https://www.foodsafety.gov/print/pdf/node/14?id=e-coli-table

| | |
|---|---|
| Sources | • Contaminated food, especially undercooked ground beef, unpasteurized (raw) milk and juice, soft cheeses made from raw milk, and raw fruits and vegetables (such as lettuce, other leafy greens, and sprouts).<br>• Contaminated water, including drinking untreated water and swimming in contaminated water.<br>• Animals and their environment, particularly cows, sheep, and goats.<br>• Feces of infected people. |
| Symptoms | • Severe diarrhea that is often bloody, severe stomach pain, and vomiting. Usually little or no fever is present.<br>• Symptoms of hemolytic uremic syndrome (HUS) include decreased urine production, dark or tea-colored urine, and facial pallor. |
| Prevention | • Avoid eating high-risk foods, especially undercooked ground beef, unpasteurized milk or juice, soft cheeses made from unpasteurized milk, or sprouts.<br>• Use a food thermometer to make sure that ground beef has reached a safe internal temperature of 160° F.<br>• Wash hands before, during, and after preparing food, after diapering infants, and after contact with cows, sheep, or goats, their food or treats, or their living environment. |

### 1.6.5. Listeria

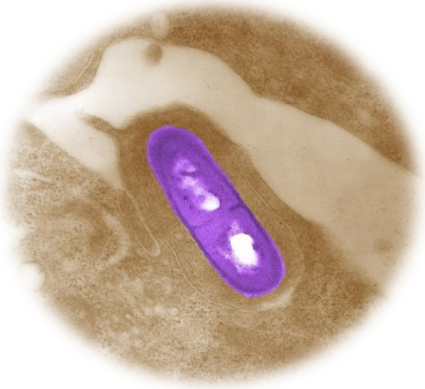


Image 1.3. Listeria monocytogenes (L. monocytogenes)
Source: https://phil.cdc.gov/Details.aspx?pid=10828

According to FDA's scientific definition, Listeria monocytogenes (L. monocytogenes) is a species of pathogenic (disease-causing) bacteria that can be found in moist environments, soil, water, decaying vegetation and animals, and can survive and even grow under refrigeration and other food preservation measures. When people eat food contaminated with L. monocytogenes, they may develop a disease called listeriosis. L. monocytogenes is generally transmitted when food is harvested, processed, prepared, packed, transported or stored in environments

contaminated with L. monocytogenes. Environments can be contaminated by raw materials, water, soil, and incoming air. Pets can also spread the bacteria in the home environment if they eat food contaminated with L. monocytogenes (FDA, 2019).

Table 1.3. See below detailed table information on Listeria
*Source:* https://www.foodsafety.gov/print/pdf/node/14?id=listeria-table

| | |
|---|---|
| Sources | • Unpasteurized (raw) milk and dairy products.<br>• Soft cheese made with unpasteurized milk, such as queso fresco, feta, Brie, Camembert.<br>• Raw fruits and vegetables (such as sprouts).<br>• Ready-to-eat deli meats and hot dogs.<br>• Refrigerated pâtés or meat spreads.<br>• Refrigerated smoked seafood.<br>• Be aware that soft cheeses made from pasteurized milk, such as queso fresco, have caused Listeria infections, most likely because they were contaminated during cheese-making. |
| Symptoms | • Listeria can cause fever and diarrhea like other foodborne germs, but this type of Listeria infection is rarely diagnosed. Symptoms in people with invasive listeriosis, meaning the bacteria has spread beyond the gut, include:<br>• For pregnant women: fever, fatigue, and muscle aches. Pregnant women may also have no symptoms but experience fetal death, pre-term labor, or infection of the newborn.<br>• For all others, stiff neck, confusion, loss of balance, and convulsions in addition to fever and muscle aches. |
| Prevention | • Do not drink raw (unpasteurized) milk, and do not eat soft cheeses made with unpasteurized milk, such as queso fresco.<br>• Heat hot dogs, cold cuts, and deli meats to an internal temperature of 165°F or until steaming hot before eating.<br>• Eat cut melon right away or refrigerate it.<br>People at higher risk should not eat the following foods:<br>• Refrigerated pâtés or meat spreads from a deli or meat counter or from the refrigerated section of a store<br>• Refrigerated smoked seafood, unless it is canned or shelf-stable or it is in a cooked dish, such as a casserole<br>• Raw or lightly cooked sprouts of any kind |

| | |
|---|---|
| | • Soft cheese, such as queso fresco, queso blanco, panela, brief, Camembert, blue-veined, or feta, unless labeled as made with pasteurized milk<br>• People at higher risk should be aware that Hispanic-style cheeses made from pasteurized milk, such as queso fresco, have caused Listeria infections, most likely because they were contaminated during cheese-making. |

### 1.7. Chemical Hazards

According to the FDA, chemical contaminants cover a broad range of contaminants including but not limited to, natural components of ingredients (e.g., some glucosinolates) or natural toxins (e.g., mycotoxins), pesticides, or industrial compounds (e.g., dioxins, melamine, etc.). Routine check is conducted under the Animal Feed Contaminants program, for chemical contaminants that are routinely checked include: mycotoxins, pesticides, heavy metals, and dioxin (FDA,2019).

Here is a list of chemical contaminants according to the FDA:

- Mycotoxins
- Aflatoxins
- Deoxynivalenol
- Fumonisin
- Ochratoxin A
- Zearalenone
- Pesticides
- Industrial Compounds
- Dioxins/PCBs
- Melamine

- Heavy Metals

According, to the FDA, their agency actively checks the levels of metals in the food supply. They have listed the following: “Metals such as arsenic, lead, cadmium, mercury and others - are found in certain foods. At high levels, these metals can be toxic, but eliminating them entirely from our

food supply is not always possible because these metals are found in the air, water and soil and then taken up by plants as they grow" (FDA, 2019).

In a greenhouse production water testing is a critical to ensure agricultural water is free from heavy metals. Later in the handbook there is "Best Practice" recommendations for heavy materials.

### 1.7.2. Chemical Hazards within a Greenhouse

Contaminants can include common household and personal care products such as toothpaste, shampoos, insect repellant, lotions, and bleach. They present associated risks to human health if they contaminate vegetable produce during harvest or production.


Image 1.4. Common household that are potential contaminants.
*Source:* https://kz.all.biz/en/production-is-chemical-household-household-g134132

### 1.8. Physical Hazards

According to the FDA, physical hazards are broadly classified as sharp hazards and choking hazards. However, these hazards can range in their sizes and hardness which can determine the

level of injuries. Injuries from physical hazards may include oral cavity damage (e.g., tooth damage or laceration of the mouth or throat), laceration or perforation of the gastrointestinal tract, and choking. In addition, filth, separate from its biological risks (feces, bug parts, etc.) are a physical hazard (FDA, 2019). It is important all growers and handlers are aware of their working environment. In a vegetable production system growers and handlers should follow strict safety guidelines on personal items. These items include jewelry, clothing items, loose buttons, or medication while conducting their duties to prevent contamination of produce.

Listed here are physical hazards found in greenhouses:

- Stones – could enter the workspace on shoes
- Wires – broken trellising wires
- Springs (from broken equipment)
- Nuts and Bolts – possible from loose tools or equipment
- Glass – possible from broken louvers or greenhouse structure

Other examples of physical hazards can be seen in (Illustration 1.1).

### 1.8.1. Other Physical Hazards


Illustration 1.1. Physical Hazards in Foods
Source: https://medcraveonline.com/JNHFE/images/JNHFE-09-00320-g004.png

### 1.9. FDA's Food Safety Modernization Act (FSMA)

According to CDC health authorities these food safety outbreaks are preventable and as a result on January 4, 2011 President Barack Obama signed into law the Food Safety Modernization Act (FSMA) under the Food and Drug Administration (FDA). The objectives of FSMA authorizes the FDA to regulate and standardize food industry practices by improving the ways foods are grown, harvested and processed. With this mandate, all existing food safety systems are transformed from responding to food-borne illness to preventing it. Another key role of this act is to address concerns

and complexities of the Global Food System. In addition, the Food Safety Modernization Act (FSMA) covers points of compliance as well as compliance dates and provides various exemptions to support the stakeholders affected by the timely changes in the system. Overall, the main objective is to prevent food contamination for both human and animal food. The aim of this handbook is to analyze and apply the Produce Safety Rule to a greenhouse system producing lettuce in a Deep-Water Culture System (DWC). This handbook is not meant to take the place of thoroughly understanding all the FSMA regulations and requirements. For further reading visit FSMA Act link at https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-produce-safety .

### 1.9.1. *FSMA's Seven (7) Regulations*

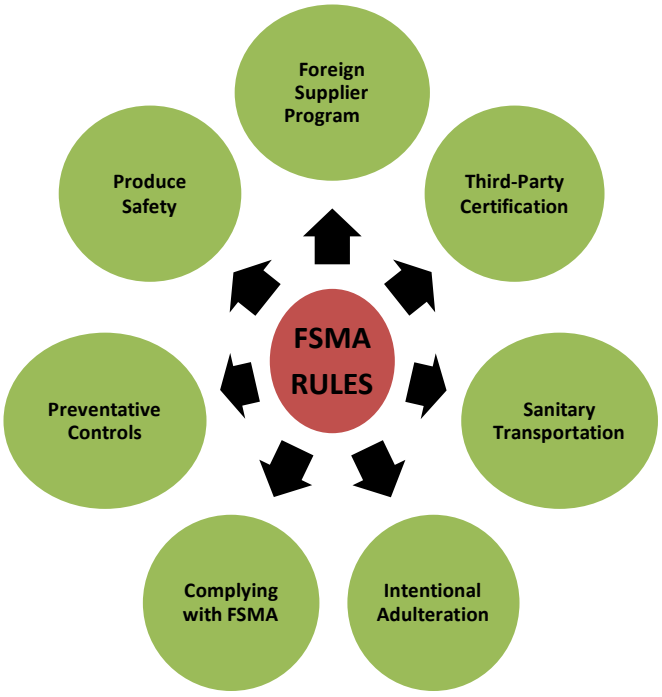



Illustration 1.2. List of the seven major rules established to implement FSMA. These rules address the various complexities in the global food supply chain.
Source: Olu Roberts

The FDA's implementation of FSMA created seven (7) major rules which created new requirements and responsibility for the implementation, prevention, monitoring and responding to food safety issues. (see Illustration 1.2)

**The seven rules are as follows:**

- Preventative Controls Rules for Human and Animal Food
- Foreign Supplier Verification Program (FSVP) Rule
- Accredited Third-Party Certification
- Sanitary Transport Rule
- Intentional Adulteration Rule
- Produce Safety Rule
- Complying with FSMA

### 1.9.2. Produce Safety Rules

It is imperative to understand how these requirements affect your operations specifically in the greenhouse environment. The hydroponic production environment naturally has many microbial risks, so every grower and handler need to know how to identify and reduce these risks. The FSMA Produce Safety Rule establishes, for the first time, science-based minimum standards for the safe growing, harvesting, packing, and holding of fruits and vegetables grown for human consumption. (FSMA, 2019) The Produce Safety Rule applies to all field agricultural production settings including outdoors in field and indoor production systems such as controlled environment

agriculture. Additionally, the produce rule is divided into key requirements to prevent food-borne contamination in the food production chain.

These requirements are:

- Agricultural Water for Pre- and Postharvest Uses
- Biological Soil Amendments
- Raw Manure
- Stabilized Compost
- Sprouts
- Domesticated and Wild Animals
- Worker Health, Hygiene, and Training
- Equipment, Tools, Buildings, and Sanitation

### 1.9.3. Exemptions

According to FSMA's regulations there are conditions that provides exemptions to certain producers. These conditions and exemptions are dependent on other factors (FSMA, 2019). To learn more about these exemptions, conditions and other requirements that would apply to your industry or farm type consult the full FSMA Law, Rules and Guidance for your related industry here at FDA's website: https://www.fda.gov/media/94332/download.

FSMA Definitions for Exemptions

- Covered – It is mandatory for one to comply with the produce rule.
- Exempt – It is not mandatory to comply with the produce rule.
- Qualified Exemption – It is NOT mandatory to comply with the produce safety rule, but only if one meets certain conditions or qualifiers.

**IMPORTANT!!!! Exemption, Does Not Relieve You from Liability**

### 1.9.4. What Determines Coverage?

According to FSMA's website on exemption these are the following categories is used to determine exemption coverage: Farm, Facility and Mixed-Type Facility.

- Farm – Recommend the use of FSMA Produce Rule and Good Agricultural Practices
- Operations Type is defined by the minimal processing capability of their farm for example: drying, baling, and vacuum packing. Therefore, there is no significant alterations being done to produce.
- Facility – Recommend the use of FSMA Preventative Controls Rules.
- Operating Type is determined by more than the minimal processing capabilities of their farm. Therefore, significant alteration is conducted. However, if facility is considered a manufacturer if it does processes such as grinding, chopping, and pelletizing. This facility is required to be registered with the FDA.
- Mixed-type Facility – This is a full functional facility that operates as a farming and processing operation. This facility is required to be registered with the FDA.

To learn more about FSMA's Exemption Policies consult (Table 1.4) or website here at link: https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-produce-safety .

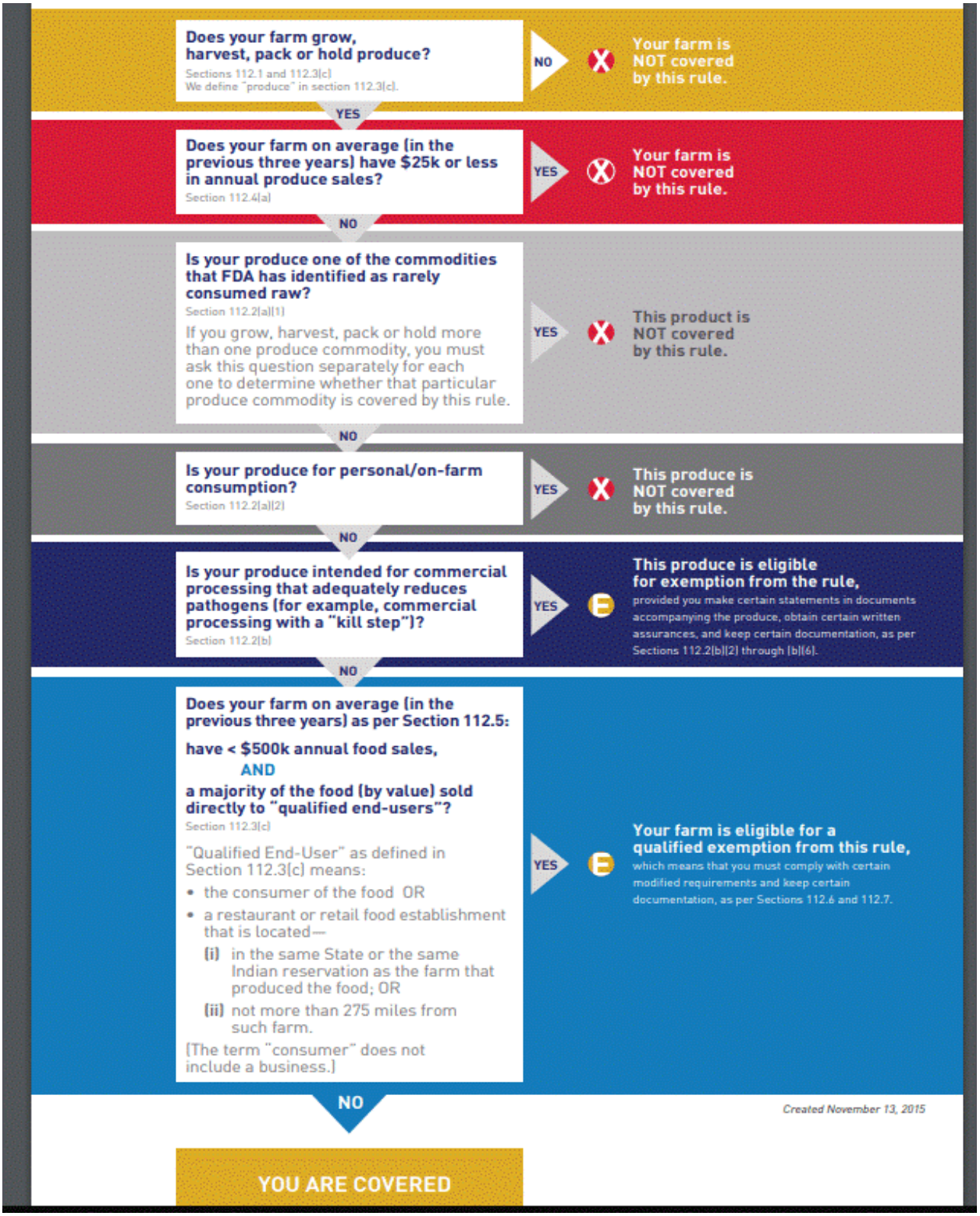



Table 1.4 Used for Standards for Food Safety. Coverage and Exemption/ Exclusions for 21 Part 112 of FSMA's Act

# Food Safety Handbook

# Guidelines on Agricultural Water for Deep Water Culture Hydroponic Systems

CHAPTER TWO

# Food Safety Handbook

## 2.1. Deep-Water Culture (DWC) Hydroponics

The Deep-Water Culture (DWC) plant production in closed systems is also identified as ponds, deep flow hydroponics, and raft systems. In the design of a DWC system, a rectangular tank less than one foot deep is filled with a nutrient rich solution in which plants are floated using Styrofoam boards. (see Image 2.1) In the DWC system a rockwool media is used to start the seeds in a nursery and at eighteen (18) days old are ready for transplant. These rockwool cubes are inserted in the styrofoam rafts and left to grow. The plant roots through the rafts and are suspended in the nutrient solution. (see Image 2.2) A closed system has a variety of parameters to be monitored for the growing of the plants. These parameters include aeration, water quality, nutrient solution pH, dissolved oxygen (DO), electrical conductivity (EC), and water levels.

Image 2.1. Lettuce 26 days after transplanting in raft culture ready to harvest.
Note the white, healthy roots. They are supported by Styrofoam boards.
(Courtesy of CuisinArt Resort & Spa, Hydroponic Farm, Anguilla, B.W.I.)
Source: Hydroponics Photo Album – Dr. H.M. Resh – Hydroponic Food Production

However, the most critical of all the parameters are the oxygen, water, and nutrients. The roots are submerged in the water solution and needs to be oxygenated. This is done using an air stone or air pump. The water is used to replace soil as the growing media through which plants take up their nutrients from the water solution. The nutrients are normally provided by a mix of micro and macro nutrients necessary for plant metabolism and growth.

These parameters are essential to the safe operations and it is important to understand how these parameters affect your greenhouse environment. For this handbook we will be focusing on the greenhouse production of lettuce using a DWC system.

Advantages of a Deep-Water Culture

- Easy to setup and start production if compared to other systems.
- Incredibly minimal maintenance, but parameters must be understood.
- In comparison to soil media, the DWC system is fast-growing.
- With raft system less moving of the plants, i.e. Labor saving (see Image 2.1).

Challenges

- Electric outage can disrupt air-pump and prevents oxygenation of plant roots.

- Shallower system has limited buffer for water conditions such as temperature, pH, and water levels.
- Hydroponics is susceptible to algae growth which will occur throughout the production stages.
- Algae harbors pest and contributes to the depletion of oxygen in the water. All Algae must be disinfected and kept at manageable levels.

Image 2.2 Lettuce in rockwool cubes at eighteen (18) days old to be transplanted.
(Courtesy of CuisinArt Resort & Spa, Hydroponic Farm, Anguilla, B.W.I.) Source: Hydroponics Photo Album – Dr. H.M. Resh – Hydroponic Food Production

Shown in (Image 2.3) lettuce on Styrofoam floats in a Deep-Water Culture (DWC) production system. A DWC system is very efficient in growing space and is popular among commercial hydroponic lettuce or vegetable production systems.

Image 2.3 Lettuce on Styrofoam rafts floating in a Deep-Water Culture (DWC)
Source: Suncrestusa.com, *http://www.suncrestusa.com/dwc-hydroponics*

Image 2.4
A DWC styrofoam rafts contaminated by algae growth.
Sources: BioSafe Systems, http://www.biosafesystems.com/wp/wp-content/uploads/2019/03/IMG_7539.jpg

As displayed the image above algae growth can occur in a DWC raft system. Additionally, these systems have other microbial risks. In a DWC common pathogens are Pythium and Fusarium are dispersible by the nutrient solution; it is essential that growers and handlers receive frequent training to become knowledgeable about these risks. Therefore, identifying and preparing for these risks will help to define the food safety program necessary for the respective production system.

### 2.1.2. Maintaining a DWC Hydroponic Production System

Maintaining a DWC system in a hydroponic production is critical, in line with Professor Neil Mattson of Cornell University CEA program,

“In the DWC system the larger volume of water provides a stable environment for things such as pH, fertilizer concentration, and water temperature in comparison to say the NFT systems. NFT systems there can be dramatic hourly changes compared to the NFT” (Urbanagnews, 2017).

### 2.1.3. Guidelines for Food Safety Planning for the DWC Hydroponic Production System

The greenhouse-controlled environment has significant advantages over field grown systems, such as deceased potential for certain wild animals, but is still susceptible to food safety risk and outbreaks. Therefore, it is important that growers and handlers understand the unique food safety risks and the various sources of contamination. In order to implement a food safety plan or program, it’s important for users to be able to identify these food safety risk. Below we suggest best practices in developing a food system.

**Important Information**

In this handbook we will list Standard Food Safety Parameters (SFSP) which are incorporated using best practices and guidelines from food safety programs such as the Cornell Good Agricultural Practices (GAP), and the FSMA Produce Rule. Note that suggested practices are not one size fits all, but a standard guideline approach in developing a food safety system. The Food

Safety Plan (FSP) is categorized into four (4) stages. The stages are risk assessment, creating the food safety plan, implementation, and reviewing.

1. Risk Assessment

   This involves the analysis of the potential risk, determine how high or low these risks are, and how these risks will be addressed.

2. Creation of the Food Safety Plan

   Using the SFSP system the following areas are addressed: Accountability, Agricultural Water Use, Soil Amendments, Workers Safety, Personal Hygiene and Training, three (3) Hazards, Inputs, Storage and Handling of Materials, Post-Harvest Handling, Traceability and Record Keeping, Recalls, and Equipment, Tools and Buildings.

3. Implementation

   This outlines the who, what, how, and when of the Food Safety Plan design. Consequently, traceability is essential to food safety, and this requires someone to be accountable for the planning and training involved with the process. This person will decide what needs to be in the plan, how it will be done, and how often. Also, the decision of when it needs to be done. It is recommended that Standard Operating Protocols (SOP's) be created for a standardized system that can be understood by all who uses them regardless of their job responsibilities.

4. Review

   After the plan is created, implemented, and evaluated. There must be continuous follow-up and assessment of the plan to make sure its successful.

### 2.1.4. The SFSP Parameters used in developing a Food Safety Plan

- Accountability
- Agricultural Water Use
- Soil Amendments
- Workers Safety
- Personal Hygiene and Training
- Hazards
- Agriculture Inputs
- Storage and Handling of Materials
- Post-Harvest Handling
- Traceability and Record Keeping
- Recalls
- Equipment, Tools and Buildings

## 2.2. Guidelines for Food Safety Plan for Deep Water Culture Hydronics

**Disclosure:** The guidelines recommended in this handbook have been adapted from the USDA GAP Audit and Verification Checklist.

Prepared by Olu Roberts

The verification checklist document is accessible at USDA.gov webpage.

Source: https://www.ams.usda.gov/sites/default/files/media/GAPGHPChecklist.pdf

## 2.3. General Information

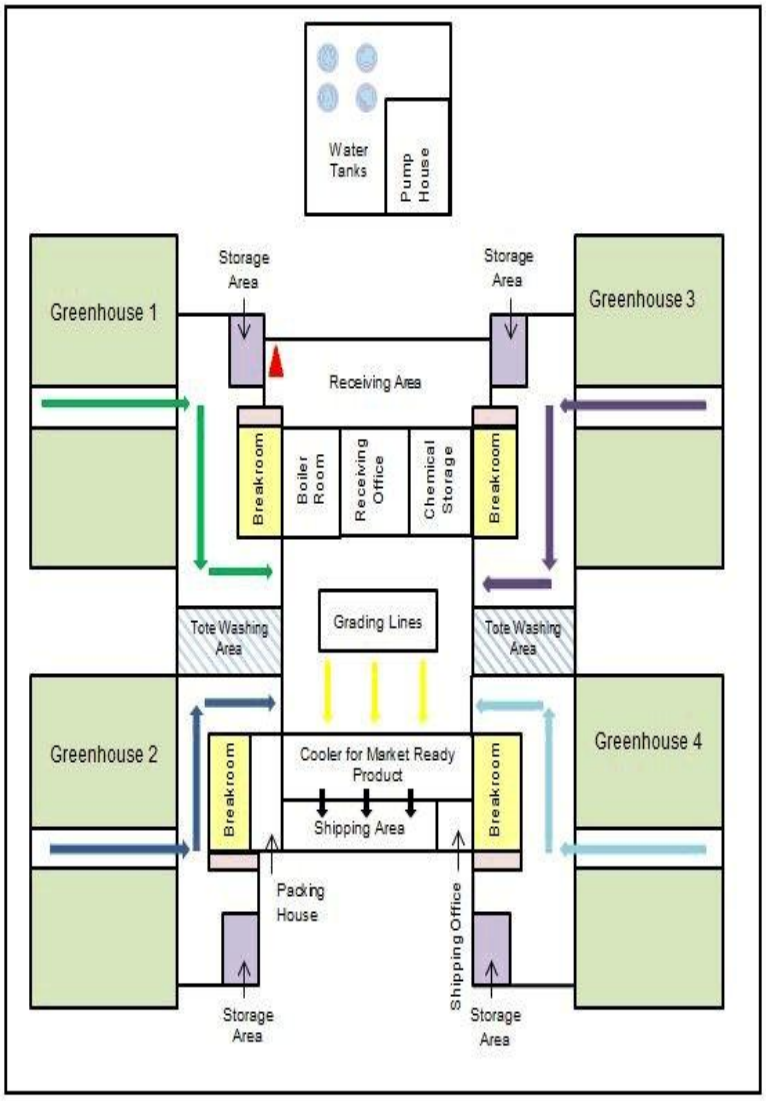
### 2.3.1. Greenhouse Description

A map of the greenhouse and its farm operations should encompass the following:

- A map should accurately represent the greenhouse farming operations. Greenhouse Description (type, and structural design) and or greenhouse description.

- Must have legal description/ GPS/ Lat.& Long. of the location. This is essential for properties with multiple greenhouse locations.
- Must have a floor plan of the greenhouse outlining total production areas, packing facility, storage areas, employee work and break areas, restrooms, water source and septic systems.
- Must identify by location types of crops in their respective production areas within the greenhouse.
- Must have a map of the packing house facility (s) indicating flow of product, storage areas, cull areas, employee break rooms, restrooms, and offices.

- Must have a greenhouse production layout of crops planted. (see Illustration 2.1)



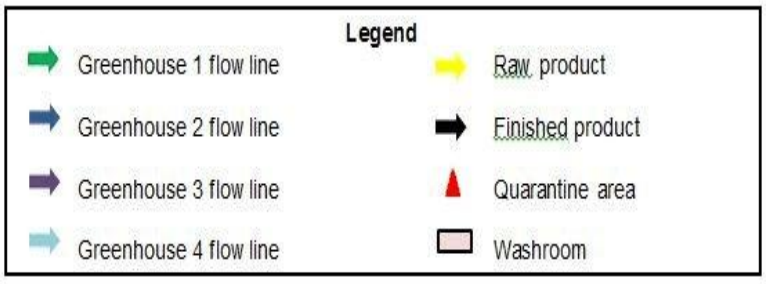




Illustration 2.1
is an example of a map for a place of production. The figure includes four water tanks, a pump house, four greenhouses, four storage areas, four breakrooms each with a washroom, two tote washing areas, a receiving area that includes a quarantine area, a boiler room, a receiving office, a chemical storage, an area for the grading area, a cooler for market ready product, a shipping area, a shipping office and a packing house.

There are arrows from each greenhouse through to the grading lines to indicate the traffic flow. There are also arrows indicating the flow of raw product from the grading lines to the cooler for market ready product. Arrows indicate that the finished product flows from the cooler for market ready product to the shipping area.

Source:
http://www.inspection.gc.ca/plants/plant-pests-invasive-species/biosecurity/greenhouse-vegetable-sector-biosecurity-guide/eng/1484722296145/1484722331070?chap=6

### 2.3.2. Accountability

- Personnel with food safety training should be designated with the responsibility of administrating a food safety program.
- All employees must be aware of who is responsible for all food safety concerns.
- A twenty-four (24) hrs. emergency contact must be available for the personnel responsible for food safety at a facility.

### 2.3.3. Traceability

Traceability plans are not required under the FSMA Produce Rule. However, it is recommended to have a produce food safety plan. This should be continuously monitored and revised accordingly in order to be effective. The benefits of this system it helps to provide a safety net, for both producers and consumers. This should include the following:

- Should have information throughout the entire production stage. The more information available the more efficient the system will be. This should include the purchase date of seeds, supplier's information, date planted or transplanted (this should include batch plantings), harvest date (or group of dates), crop flow into storage until sent to market.
- Should develop and establish a system for lot coding. Lot coding shows the characteristics, such as the crop, variety name, color codes, and dates.

Information that could be included in a lot code:

Greenhouse name and/ or room number

Field/block of origin

Inputs applied

- Harvest date
- Harvest Personnel (s)
- Packinghouse used
- Packing date
- Packing Personnel (s)

- Cold Storage used
- Packing Supplies should also have a batch number system (highly recommended)

*Important: See Food Safety Handbook appendix. For example, in Establishing Lot Codes*

**2.3.4. Recall**

As with the traceability system a Recall Plan is not a requirement according to the Produce Rule. However, a required mock recall is recommended by USDA-GAP. The records should be accessible to buyers of your produce. According to USDA, ‘’Good Agricultural Practices (GAP) is a voluntary audit that verify that fruits and vegetables are produced, packed, handled, and stored as safely as possible to minimized risks of microbial food safety hazards’’ (USDA, 2002). By using the GAP checklist method, a grower can verify the challenges within their food safety planning and how prepared it will be. Additionally, if you have developed a produce traceability system, you will need a method to evaluate it.

Important: Visit the University of Massachusetts Center for Agriculture resource webpage for more information on traceability and mock recall systems.

https://ag.umass.edu/resources/food-safety/for-farmers/farm-food-safety-plans-traceability

Record Keeping (Documentation)

- All food safety plan should have updated documentation, records of procedures, SOP’s, and polices.
- All documentation should be in a safe, accessible, place and available if requested for inspection.
- The person responsible for keeping documentation should train other persons to support the documentation system in case of their absence or an emergency.

**2.6. Standard Operating Procedures**

### 2.6.1 Worker Health and Hygiene

Cross-contamination is a major hazard in food safety. The employer is responsible to provide the training, equipment, and relevant notices to ensure outbreaks. The training of employees in the proper health and hygiene practices can significantly reduce an outbreak. It is imperative employees are aware of and should able to identify potential hazards. For example, see figure 2f.

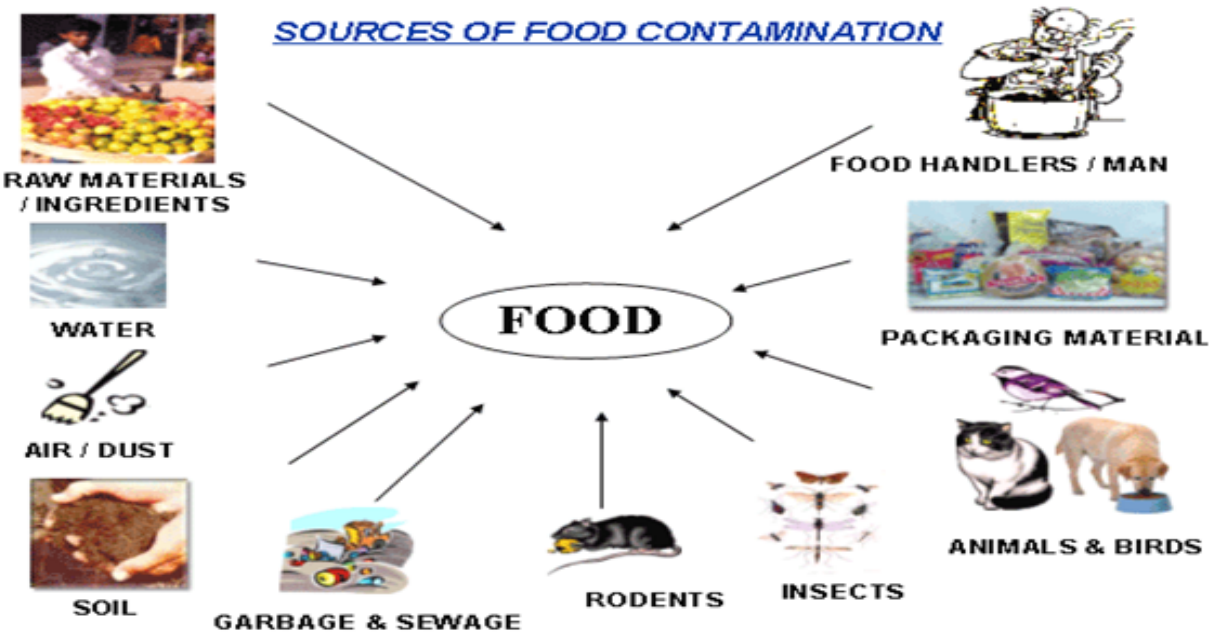



Illustration 2.2. Sources of Food Contamination
Source: https://medcraveonline.com/JNHFE/images/JNHFE-09-00320-g001.png

There are sources of food contamination which employees should also be aware of in their production systems. A list of recommended practices to avoid food contamination is shown below.

Best Practices

**2.6.2. Hand Washing** Growers and handlers must have access to potable water.

- All growers and handlers at the location must follow proper hygiene and sanitation practices.
  - Such as hand washing, wearing protective clothing in production areas, report any injuries.
  - Employers must conduct frequent training for their employees.
- Comprehensible signs should be posted in areas frequented by employees for example, the breakroom, water coolers, and restrooms) reminding and instructing them to wash their hands properly before returning to work.
- All visitors to the location should be briefed on the food safety policies and are required to follow proper sanitation and hygiene practices.
  - Visitors should be provided with protective equipment and briefed on the food safety requirements.
  - Visitors should disclose any health-related issue that could jeopardize food systems at the visiting site.
  - Visitors should have access to potable water at all time.
  - Visitors should have access to clean, hygienic restrooms and hand-washing stations.
- All visitors should be logged with their date, time of arrival, and departure. Staff must accompany visitors on every visit.
- Employees and visitors should avoid wearing jewelry or other objects on the body which are potential hazards.
- It is recommended that employees not wear regular clothing to the production areas to avoid hazards. Instead, employees must be provided industry standard personal protective equipment (PPE) and/or outer clothing. This will provide a barrier between the employee

and the vegetable produce and reduce contamination. For example: gloves, aprons, rain boots, hairnets, and other proper equipment should be worn.

- Frequent inspection is necessary to ensure equipment is in good, safe working order. This includes provision of proper sanitary procedures for employees to have their PPE's cleaned or replaced.
- Workers must keep clean and cut nails and personal hygiene.
- PPE's worn in the production areas should remain there when moving to non-production areas.
- Glass bottles, cans, cups, and items made of glass should not be allowed in production areas. Because if broken or contents spilled in production that becomes a hazard.
- All toilets/ restrooms must have potable water for hand washing, stocked with toilet paper, individual use towels, and hand soap or anti-bacterial soap. A recorded log must show the scheduled servicing and cleaning.
- Harvest bins should be used for production purposes and not personal use.

All employees must have proper sanitation and hygiene practices. Employee working in packaging and production areas must wash their hands before beginning and returning to work. The CDC has recommended a standard procedure for handwashing. See Figure 2g. In Food Safety appendix no. 4 For example, of CDC recommended handwashing procedure.

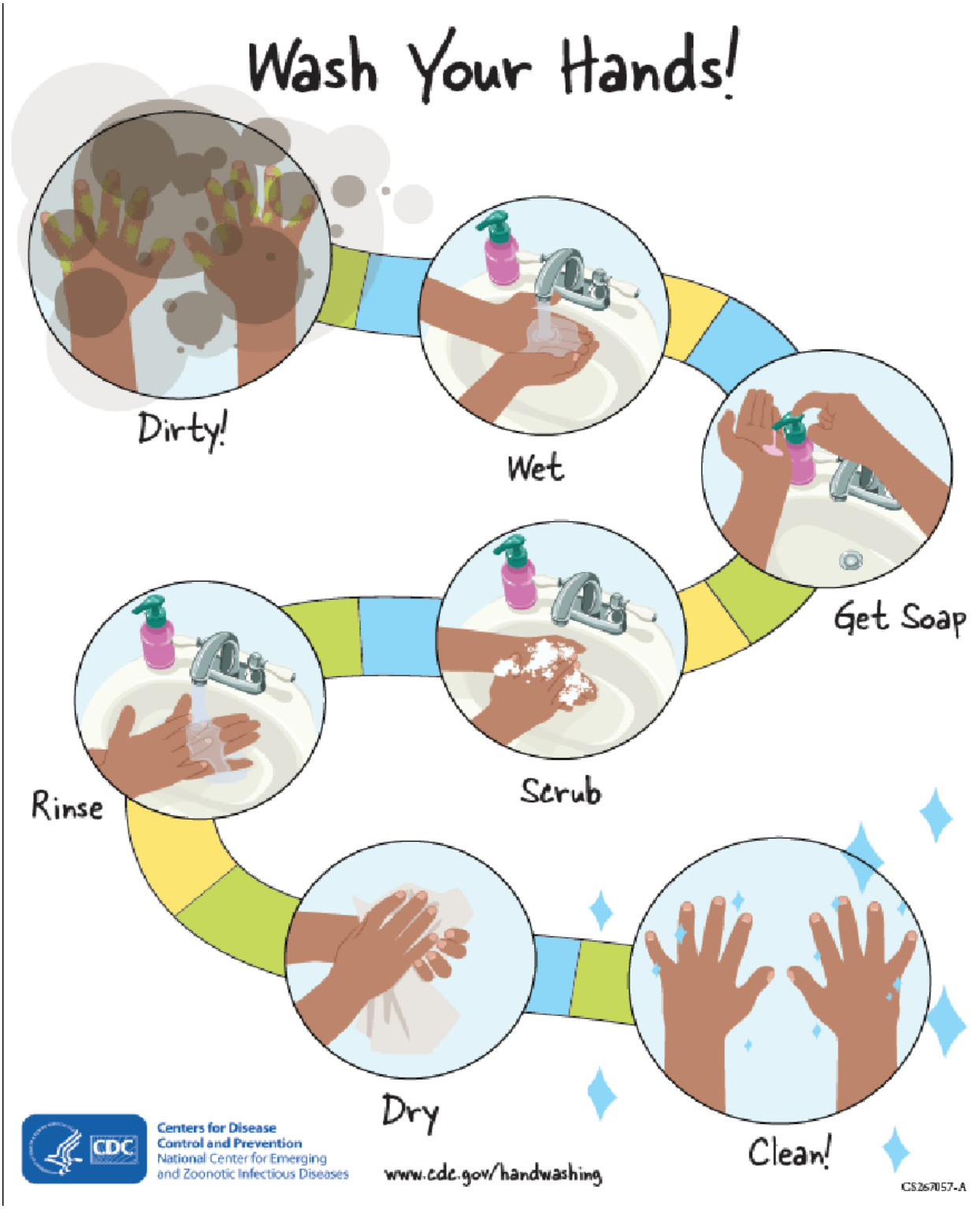



Illustration. 2.3 CDC Handwashing recommended procedure.
Source: https://www.cdc.gov/handwashing/pdf/wash-your-hands-steps-8x11.pdf

### 2.6.3. Worker's Illness and Accident Procedures

- Workers with diarrheal disease or symptoms of other infectious disease must not handle fresh produce and recommended to avoid all production related activities.
- Workers must know the emergency procedures, first-aid stations and who to report their injuries. There must be a policy that addresses employees injured on the job.
- Policies should to address the handling/disposition of produce or food contact surfaces that becomes exposed to blood or bodily fluids. This includes the documentation and sanitization procedures.
- Workers should seek prompt treatment with the time-off to recuperate from any injuries received.
- Injuries that result in an open wound should be documented and prompt treatment must be sought.
- All abrasions or open wounds must have treatment and report made to supervisors.

### 2.6.4. Water Usage

Potable Water

As outlined in the workers hygiene section, employees must have access to potable water. This includes breakroom drinking areas, showers, hand washing, toilets, and restroom use.

**Agricultural Water**

Water is the most essential part of the Deep Water Cultured (DWC) hydroponic system. The operations of any hydroponic farming systems are dependent on the following parameters to guarantee the safe and efficient use of water in vegetable production. The source of the water used in production must have a record and properly documented. This could be pond, stream, well, or municipal water. However, municipal source is treated as potable water and is the preferred choice and recommendation for hydroponic systems.

Additionally, an efficient filtration system should be used to filter out particles or unwanted mineral elements. Some municipal water mineral content can affect pH and EC levels within the production water system. Whatever water source is used some standard operating procedures

(SOP's) must be followed to ensure safe hygienic agricultural water use in the food production system. For example, before adding water to any hydroponic system the following procedures is recommended:

Water Quality

Water quality assessment must be conducted to determine the quality of the water for the intended irrigation purposes and strict procedures must adhere its monitoring.

Requirements for Water Quality

According to the FSMA agricultural water rule, it establishes **two sets of criteria** for microbial water quality, both of which are based on the presence of generic E. coli, which can indicate the presence of fecal contamination (FSMA, 2019).

According to FSMA it lists the requirements for Water Quality as:

- No detectable generic E. coli are allowed for certain uses of agricultural water in which it is likely that potentially dangerous microbes, if present, would be transferred to produce through direct or indirect contact. Examples include water used for washing hands during and after harvest, water used on food-contact surfaces, water used to directly contact produce (including to make ice) during or after harvest, and water used for sprout irrigation. The rule shows that such water use must be immediately discontinued, and corrective actions taken before re-use for any of these purposes if generic E. coli is detected. The rule prohibits use of untreated surface water for any of these purposes (FSMA, 2019).

- The second set of numerical criteria is for agricultural water that used for growing produce (other than sprouts). The criteria are based on two values, the geometric mean (GM) and the statistical threshold (STV). The GM of samples is 126 or less CFU of generic E. coli per 100 mL of water and the STV of samples is 410 CFU or less of generic E. coli in 100 mL of water (FSMA, 2019).

**Requirements for Testing**

According to FSMA's requirement for agricultural water rule.

- It adopts the general approach to testing untreated water used for certain purposes proposed in the supplemental notice, with changes. The rule still bases testing frequency on the type of water source (i.e. surface or ground water) (FSMA, 2019).

According to FSMA's requirement for agricultural water testing,

- In testing untreated surface water—considered the most vulnerable to external influences—that is directly applied to growing produce (other than sprouts), the FDA requires farms to do an initial survey, using a minimum of 20 samples, collected as close as is practicable to harvest over the course of two to four years. The first survey findings are used to calculate the GM and STV (these two figures are referred to as the "microbial water quality profile") and determine if the water meets the required microbial quality criteria. (FSMA, 2019).

**Frequency of Testing**

According to FSMA's requirement for frequency in testing agricultural water,

- After the first survey has been conducted, an annual survey of a minimum of five samples per year is required to update the calculations of GM and STV.
- The five new samples, plus the previous most recent 15 samples, create a rolling dataset of 20 samples for use in confirming that that the water is still used appropriately by recalculating the GM and STV.
- For untreated ground water that is directly applied to growing produce (other than sprouts), the FDA requires farms to do an initial survey, using a minimum of four samples, collected as close as is practicable to harvest, during the growing season or over a period of one year.

The first survey findings are used to calculate the GM and STV and determine if the water meets the required microbial quality criteria.

- After the first survey has been conducted, an annual survey of a minimum of one sample per year is required to update the calculations of GM and STV.
- The new sample, plus the previous most recent three samples, create a rolling dataset of four samples for use in confirming that that the water is still used appropriately by recalculating the GM and STV.
- For untreated ground water that is used for the purposes for which no detectable generic E. coli is allowed, the FDA requires farms to initially test the untreated ground water at least four times during the growing season or over a period of one year. Farms must determine whether the water can be used for that purpose based on these results.
- If the four initial sample results meet the no detectable generic E. coli criterion, testing can be done once annually thereafter, using a minimum of one sample. Farms must resume testing at least four times per growing season or year if any annual test does not meet the microbial quality criterion.
- There is no requirement to test agricultural water that is received from public water systems or supplies that meet requirements established in the rule (provided that the farm has Public Water System results or certificates of compliance demonstrating that the water meets relevant requirements), or if the water is treated in compliance with the rule's treatment requirements (FSMA, 2019).

**Best Practices**

- All necessary steps to protect irrigation water from potential direct and non-direct point source contamination.
- All water sources from wells are to be assessed by a certified laboratory once a year and surface water assessed quarterly.
- Employees must be provided with potable water at all time.
- Irrigation water must be assessed for chemical or dangerous substances.
- Record Keeping
- Water testing records and results for all sources must be documented. This includes water for human consumption, irrigation, and post-harvest application.

### 2.6.5. Sanitization for the DWC Hydroponics System

- It is recommended before starting and setting up production system the planned working areas must be sanitized.
- After crops have been harvested from the DWC system all the sections of the system should be disassembled and sanitized. This include:
- Air-Stones – can be submerged in a solution of bleach and water to sanitized moving parts.
- Styrofoam rafts – should be scrubbed with a bleach and water solution.
- Water in the DWC system may be used for several crop cycles. But the rafts should be inspected and sanitized if deemed necessary.
- Irrigation system should be check for algae and sanitized.
- Over the production stages checks should be done to ensure system is maintained.
- Records should be kept of inspections and actions taken if any.
- All efforts must be made to keep hydroponic systems and components clean to prevent contamination. Photo of Figure 16. represent a cleaned system prior to production.

Image 2.5. Example of a clean DWC System
*Source: https://university.upstartfarmers.com/blog/intro-aquaponic-raft-system*

### 2.6.6. Animals/ Wildlife/ Livestock

- Crop product should not be located near or adjacent to dairy, livestock, or fowl production facilities unless adequate barriers exist.
- Manure lagoons located near or adjacent to crop production areas are to be maintained to prevent leaking/overflowing. Additionally, it is recommended that measures be taken to prevent runoff from contaminating production areas.
- Livestock must be restricted from the source of irrigation water for crop production.
- Barriers should be in place to prevent wildlife from entering crop production areas.
- Vented greenhouse should have barriers to prevent wildlife from entering the facility.

### 2.6.7. Manure and Compost

- Employees who manage manure or compost should be aware of the possibility of cross-contamination of water sources within a hydroponic system.
- All employees' boots should be sanitized before entering a greenhouse facility if they work within manure or compost areas.
- Post-Harvest Management
- Storage
- All harvesting containers and bulk hauling vehicles used for storing produce must be kept clean and frequently sanitized.
- Utensils and Equipment
- All utensils, equipment used in production must be frequently cleaned and disinfected on a scheduled basis.
- All equipment used in production must be inspected on a scheduled basis and repaired in a timely manner.
- Washing
- Water used to wash, and process fresh produce must be deemed microbially safe.
- Temperature of processing water should be monitored and kept at the temperature required for the appropriate produce.
- Water contact surfaces, such as dump tanks, wash tanks, hydro-coolers and flumes should be cleaned and/or sanitized on a schedule basis.
- Food contact surfaces must be kept clean, sanitized before and after use on a schedule basis. Additionally, documentation must be inspected and maintained for cleaning logs.
- Water use for ice and cooling produce must be potable.

### 2.6.8. Packing and Packaging Materials

- Ice used for cooling produce is manufactured, transported, and stored under sanitary conditions
- Packaging materials must be stored in a clean and sanitary location with the facility.

- All packaging materials received from external suppliers must be inspected on receipt and documentation made. Its recommended that a lot system be created for packaging materials. This will help with traceability procedures.
- Packaging areas must be safely stored upon inspection and kept free from pests, insects, and other hazards to prevent contamination.
- Harvesting containers, totes etc. are not to be used for any other purpose than what it was intended for to prevent contamination.
- Product moving for markets should be identifiable for traceability purposes in the event of a recall.

**Transportation**

- Transportation used to move produce to storage, must be inspected before and after contact with fresh produce and must be disinfected on a schedule basis.

**Record Keeping**

- A log must be kept of the daily use of the transportation and a frequent cleaning schedule.

**2.6.9. Hazards**

- Light bulbs and glass are physical hazards. Lamps must be inspected so as not to cause contamination if breakage occurs.
- SOP's should be available in case there is a biological, chemical, or physical contamination occurs during the post-harvest process.

**2.6.10. Pest Control**

- There must be a pest control program available at the production facility.
- This control program must be reviewed frequently, and logs maintained.
- Greenhouse structure should be inspected for breakage, broken glass, loose vents, for damage and repaired as soon as possible. All identified problems should be documented for traceability records and processes.

# APPENDIX

## IMPORTANT RESOURCES

- Establishing Lot Codes.
  Source: https://ag.umass.edu/resources/food-safety/for-farmers/farm-food-safety-plans-traceability

- Conduct a Mock Recall
  **S**ource: https://ag.umass.edu/resources/food-safety/for-farmers/farm-food-safety-plans-traceability

- USDA Good Agricultural Practices Good Handling Practices, Audit Verification Checklist
  Source: https://www.ams.usda.gov/sites/default/files/media/GAPGHPChecklist.pdf

- Bad Bug Book. Foodborne Pathogenic Microorganisms and Natural Toxins Handbook
  Source: https://www.fda.gov/food/foodborne-pathogens/bad-bug-book-second-edition .

- Farm Food Safety Plans and Traceability
  Source: https://ag.umass.edu/resources/food-safety/for-farmers/farm-food-safety-plans-traceability

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